ACCURATE ESTIMATION OF σ^0 USING AIRSAR DATA

Francesco Holecz * and Eric Rignot

Jet Propulsion Laboratory, California Institute of Technology,
4800 Oak Grove Drive, M/S 300-243, Pasadena CA 91109
FAX: 8183936943, E-mail: franci@blacks.jpl.nasa.gov
* on leave from Remote Sensing Laboratories, University of Zürich, Switzerland

1. INTRODUCTION

During recent years signature analysis, classification, and modeling of Synthetic Aperture Radar (SAR) data as well as estimation of geophysical parameters from SA R data have received a great deal of interest. An important requirement for the quantitative use of SAR data is the accurate estimation of the backscattering coefficient σ^0. In terrain with relief variations radar signals are distorted due to the projection of the scene topography into the slant range-Doppler plane, The effect of these variations is to change the physical size of the scattering area, leading to errors in the radar backscatter values and incidence angle. For this reason the local incidence angle, derived from sensor position and Digital Elevation Model (DEM) data must always be considered. Especially in the airborne case, the antenna gain pattern can be an additional source of radiometric error, because the radar look angle is not known precisely as a result of the the aircraft motions and the local surface topography. Consequently, radiometric distortions due to the antenna gain pattern must also be corrected for each resolution cell, by taking into account aircraft displacements (position and attitude) and position of the backscatter element, defined by the DEM data.

In this paper, a method to derive an accurate estimation of the backscattering coefficient using NASA/J PL AIRSAR data is presented. The results are evaluated in terms of geometric accuracy, radiometric variations of σ^0, and precision of the estimated forest biomass.

2. METHOD

From the radar equation for distributed targets it is known that the received power is modulated with the 2-way-antenna gain $G(\theta)^2$ and with the reciprocal value of $1/\sin\theta_i$, where θ_i is the local incidence angle. For each pixel these quantities are dependent on the radar look angle θ, the depression angle of the antenna, the sensor position and attitude, the position of the backscatter element, as well as on the processed pixel spacing in range and azimuth. Since SAR processing does not include topographic information, these two radiometric corrections are omitted during the processing step, and therefore they should be considered in a postprocessing step (van Zyl et al., 1993; Holecz et al., 1994). Figure 1 gives an overview of the required input data, and summarizes the various steps. The method is discussed in detail in Holecz et al. (1994). Note that geometric calibration does not include a geocoding of the image. It only considers the relationship> between the sensor and each single backscatter element. This, of course, can be achieved even in the original image geometry without resampling the SAR data.
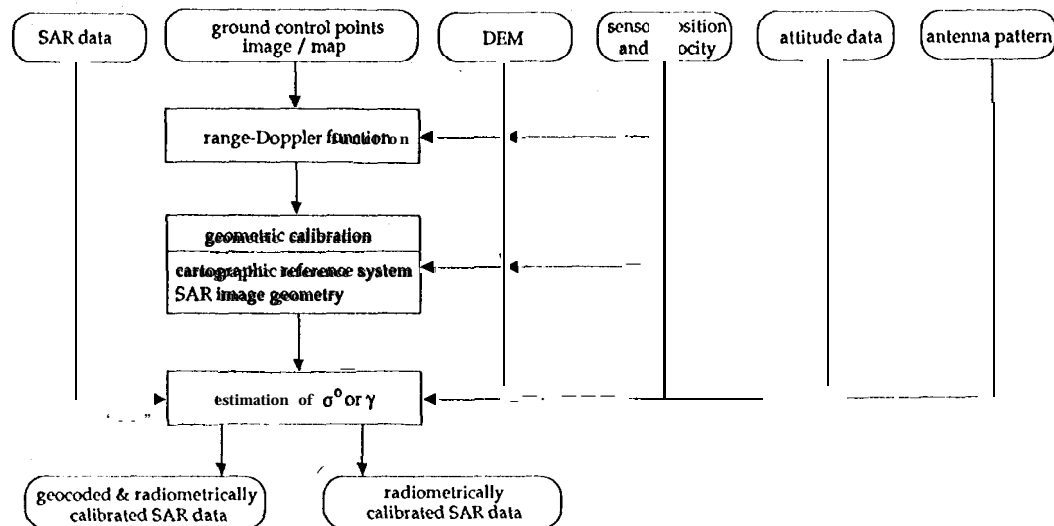

Figure 1: Derivation of the backscattering coefficient

3. DATA SETS

The SAR data used in this study were collected by the AIRSAR system on May 6 of 1991 over the hilly area (190 to 500 msl) of the Bonanza Creek Experimental Forest (64 .75°N, -148° W), near Fairbanks, Alaska. The 16-look image covers an area of around 100 km^2.

One prerequisite is the availability of DEM. For the BCEF test site only 15 minute DEM data of the US Geological Survey are available. The data were transformed from the original geographic coordinate system into the Universal Transverse Mercator coordinate system (zone 6) and resampled to 12.5 meter grid size using a bilinear interpolator.

Further required data are position and attitude data of the platform. The NASA/ARC DC-8 aircraft is currently equipped with three operational navigation systems, namely the Data Aircraft and Distribution System (DADS), the Laser Reference System (LRS), and the Six Gun Global Positioning System (SG-GPS) (DC-8 ALEII, 1990). DADS data include yaw, pitch, roll, latitude, longitude, and altitude of the aircraft above the ground, while LRS measures yaw, pitch, roll, latitude, longitude, three-dimensional velocity vector, and track angle of the aircraft. The positioning data of the third system arc stored in latitude, longitude, and altitude above sea level. DADS and SG-GPS are updated every second, while LRS updated every 0.02 second. The absolute positioning accuracy of DADS and SG-GPS is ±200 meters, while LRS can achieve a better accuracy. However, since LRS is not locked to other systems, it can drift significantly with time. Two new experimental systems are the Turbo-Rogue GPS (TR-GPS) and the Honeywell Inertial Navigation Unit (HW-INU) having an acquisition rate of 1 and 50 Hz, respectively. The positioning accuracy in real time of the TR-GPS corresponds to the SG-GPS, but in differential mode, it is in the order of ±10 cm. The data acquired by the HW-INU system achieve a positioning precision of ±3 meter and an attitude accuracy of +1/1000 degree.

4. RESULTS

Figure 2 shows the P-band total power in slant range geometry and in UTM coordinate system (zone 6), respectively. As already mentioned radiometric errors due to the topographic effects and the aircraft displacements must be additionally considered. Therefore, the local incidence angle as well as the antenna gain pattern correction were calculated and shown in Figure 3 (a-d). Since these two corrections arc carried out in the original SA R geometry (slant or ground range projection) and in the cartographic reference system,' the backscattering coefficient can be derived in both reference systems.

What arc the consequences of the topographic effects for the forest, biomass estimation? It has already been noticed in Rignot et al. (1 994) that DEM should be combined with the SAR data, in order to improve radar estimates of forest biomass in areas with topography. Here, we analyse these effects. The backseat tering coefficients at P-band for HH, VV, and HV polarization are derived taking into account to the variations of local incidence angle as well as of the antenna gain pattern using the DEM data. The forest biomass, as shown in Figure 4, is then estimated with a regression curve applied to σ^0 of the three linear polarizations.
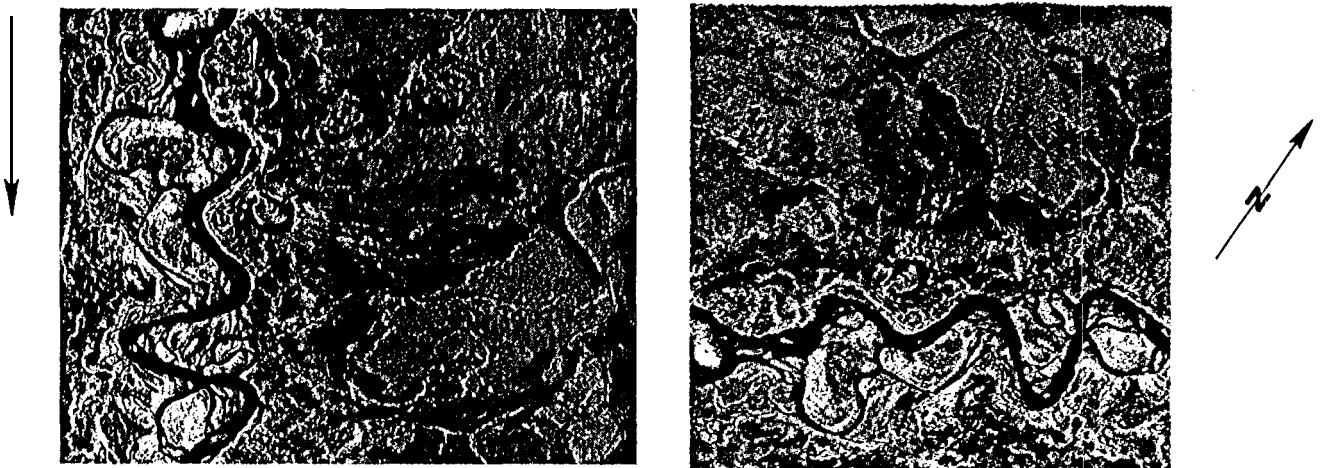
Figure 2: P-band total power in slant range geometry (left) and in UTM coordinate system (right)
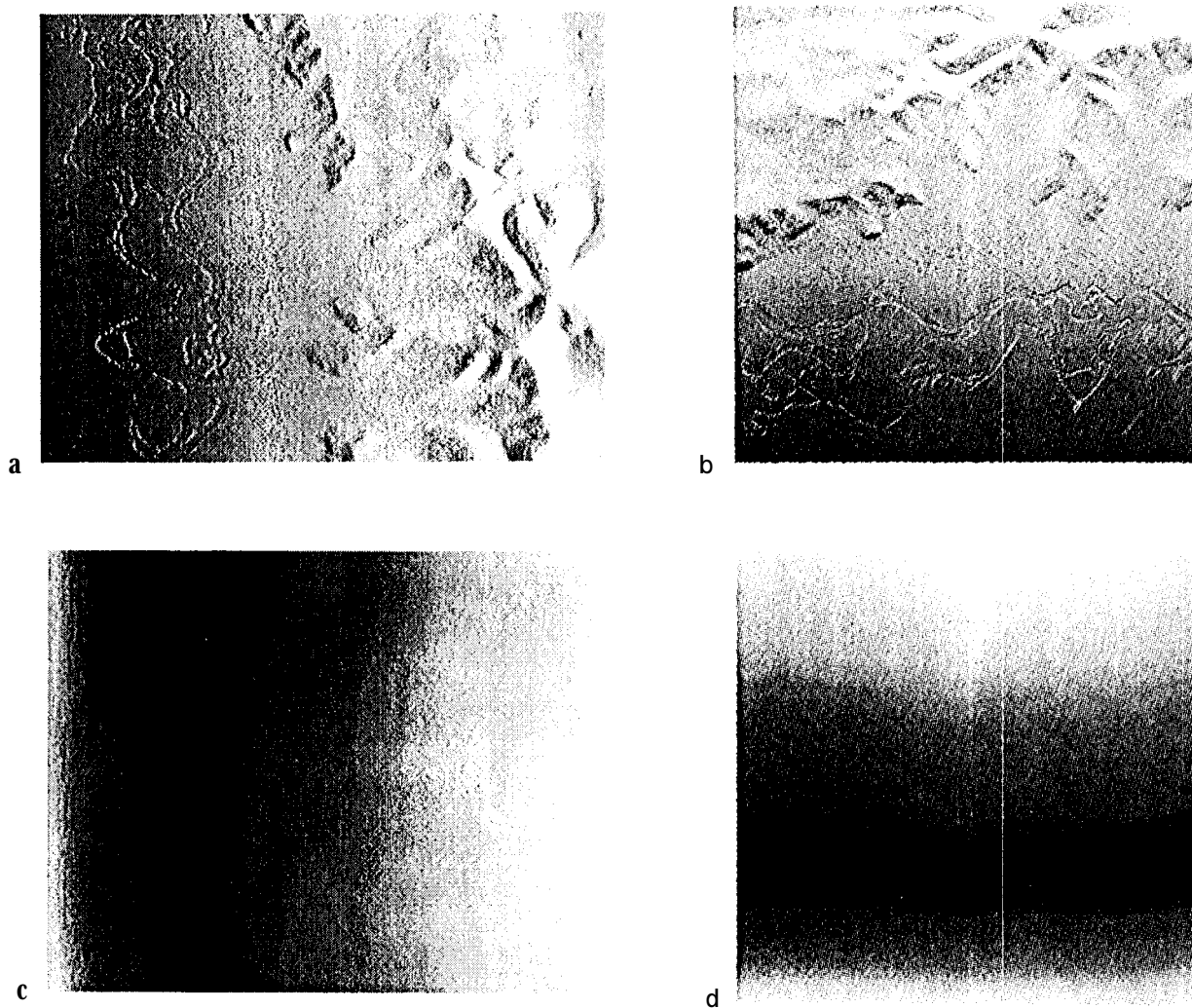
Figure 3: Local incidence angle in a) slant range geometry and b) in UTM coordinate system; Correction of antenna gain pattern at P-band HV in c) slant range and d) UTM coordinate system

Figure 4: Estimated forest biomass (tons/ha) using P-band data in slant range geometry

5. DISCUSSION OF THE RESULTS AND CONCLUSIONS

The presented results are discussed and evaluated in the following terms:

- Geometric accuracy: For an accurate estimation of the backscattering coefficient, flight path data (position and attitude), DEM, sensor and processor characteristics have been considered. This, of course, includes all the cartographic and geodetic transforms, as well as a range-Doppler approach (Meier et al,, 1993). For the Al RSA R system the positioning data collected by the three operational navigation systems during this flight showed high inaccuracies. Only DADS data could be used, with an absolute positioning inaccuracy of about 1000 meters. However, using ground control points we achieved an average geometric accuracy of the geocoded image of ±30 meters (grid size of the DEM is 12.5 meters). These deviations are due to inaccuracies a) of the operational navigation system (relative inaccuracies), b) of the ground control points extracted from a 1:63,360 scale map, c) of the low resolution of the DEM data, and d) motion errors of the aircraft not considered during the SAR processing. It must be pointed out that some AIRSA R data acquired after 1993 are already been processed taking into account motion errors of the aircraft. Furthermore the accuracy of positioning and attitude data are being improved by using the two new experimental systems mentioned in section 3. Consequently, a geometric accuracy in the order of ±1 pixel is expected.

- Radiometric variations of u": Even in a moderate hilly area as the BCEF test site, topographic effects on the radiometric calibration cannot be neglected. In fact, radiometric errors exceeding 3 dB in magnitude have been observed. The major contributions are due to the effects on the local incidence angle (up to 1.9 dB), but also local surface changes and variations of the roll angle on the antenna gain pattern correction caused radiometric errors up to 1.3 dB at P-band (HV 1.30, HH 1.25, **VV 1.34**). However, as already reported in Holecz et al. (1993), the quality of the DEM data strongly influences the radiometric calibration and therefore the accuracy of the backscattering coefficient. It has also to be noted that the topography in the SAR image is located in the far range part (see Figure 3a). Consequently, radiometric errors due to relief effects are relatively small, mainly because of the large radar look angle.

- Accuracy of the estimated forest biomass: In the biomass map shown in Figure 4 we estimated the radar-predicted values to be within 20% of actual values obtained using forest inventory and allometric equations (Rignot et al., 1994). However, this accuracy is only applicable to forest stands in the floodplains and in the south-, radar-facing, slopes in the upland forests. These stands are all imaged at an incidence angle of about 45 degrees. In the north-facing slopes, away from the radar, the radar underestimates the biomass because the incidence angle is several tens of degrees away from 45 degrees, and radar backscatter is not correctly calibrated. These errors are reduced after calibration of the SAR data using the DEM. The forest biomass of the north-facing slopes is higher and in better agreement with ground estimates. We have also estimated the dependence of radar backscatter with the incidence angle using multiple incidence angle topography -corrected data, and we have retrieved forest biomass as a function of incidence angle. Surface truth indicates that the results are now comparable in precision to those obtained in the floodplains,

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